Effect of Residue Management Methods on No-Till Drill Performance

M. C. Siemens, D. E. Wilkins

Abstract. *Excessive crop residue on the soil surface impedes drill performance and subsequent crop production in conservation tillage systems. To address this issue, 10 different residue management strategies were evaluated to determine their effect on no-till drill performance in terms of seedling establishment, early plant vigor, and crop yield. Field conditions were characterized by size, concentration, and distribution of residue. Residue management strategies included leaving tall standing stubble, using various chopping and spreading devices, and removing the residue by baling. Experiments were conducted in northeastern Oregon fields that had been previously seeded to winter wheat and produced 9.8 and 10.5 t/ha of residue in 2000 and 2001, respectively. Winter and spring wheat plots were seeded with a hoe-type no-till drill. For the residue management methods used in this study, stand establishment and seedling dry weight were reduced by 20% to 58% and 22% to 46%, respectively, when the full quantity of residue was left on the soil surface as compared to those where the residue concentration was reduced by baling. Seeding into high concentrations of residue left by non-uniform residue distribution systems also caused reductions in stand establishment and early plant growth. Long standing stubble and high concentrations of loose straw greater than 18 cm in length caused unacceptable drill plugging. Successful drill operation was achieved in crop residues exceeding 9.8 t/ha when stubble height was less than or equal to row spacing and the majority of cut straw was cut into pieces less than 18 cm long. Although consistent yield differences were not found, the results of this study showed that residue concentration and size have an important influence on no-till crop yield potential and drill operation.*

Keywords. *No-till drill, Direct seeding, Drill performance, Residue management, Seedbed preparation, Seedling emergence, Wheat, Crop production.*

The dryland grain growing region of the inland Pacific Northwest encompasses approximately 3.7 million ha. Average annual soil losses in this area range from 5 to 50 t/ha (Zuzel et al., 1982), exceeding USDA soil loss tolerance limits of 2.2 to 11.2 t/ha for sustained economic soil productivity (Renard et al., 1997). Utilization of conservation tillage systems such as no-till that leave more than 30% residue cover on the soil surface reduces soil erosion by 90% as compared to conventional, full inversion tillage systems (Veseth et al., 1986; Papendick, 1998). No-till farming systems, however, are practiced on only 7.5% of the farmland in the inland Pacific Northwest (Conservation Technology Information Center, 2002). Limited adoption of this practice is due not only to economic and agronomic concerns (Veseth and Wysocki, 2003; Young and Upadhyay, 2003), but also to the lack of trouble free, reliable seeding equipment for planting into the high residue concentrations ranging from 3 t/ha to more than 10 t/ha encountered in this region (Lindwall and Anderson, 1977; Erbach et al., 1983; Hyde et al., 1987; Wilkins et al. 1992; Slattery and Riley, 1996; Siemens et al., 2004). Siemens et al. (2004) discussed the problems associated with drill performance when seeding into heavy concentrations of residue and the research efforts to overcome these issues. The major limitation of hoe-type drills is their propensity to plug in heavy residue, causing operator frustration, reductions in field capacity, and large piles of residue to form behind the drill that cover the seed row and suppress seedling growth. Disc-type drills tend to have poor seed placement because the openers push residue into the seed furrow or ride on top of the residue and place seed on the soil surface. Equipment modifications to overcome these problems have included increasing the spacing between openers by increasing row spacing or adding tool bars, use of various row cleaning devices and attachments such as coulters to cut through the residue ahead of the furrow openers. Despite these efforts, a consensus indicates that there is a lack of reliable, optimally performing seeding equipment for sowing into residue densities exceeding 2.5 to 4.5 t/ha (Erbach et al., 1983; Slattery and Riley, 1996; Siemens et al., 2004).

Given the limitations of design modifications of modern no-till seeding equipment, another approach is to manage the size, condition, and distribution of crop residue in a way that effective drill performance can be obtained. Previously reported research results indicate there is merit to this approach. Allmaras et al. (1985) measured the residue distribution patterns of 12 combines during wheat (*Triticum* aestivum L.) harvest and found that concentrations of residue varied by a factor of 1.4 to 5.1 across the header width depending on combine and residue distribution system. They suggested that to obtain unimpeded no-till drill performance, a difference in residue concentration of less than 50% across

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the header width is needed; however no studies were carried out to support this claim. Rasmussen et al. (1997) reported that winter wheat and spring wheat yields were 13% and 5% lower, respectively, when seeded into 30- to 40-cm tall standing stubble as compared to crops planted into stubble that had been finely chopped or burnt. Because reductions in crop yield were most likely due to reduced interception of sun light, lower soil temperature, or increased pathogen activity, they suggested that flattening or removal of crop residue may be necessary to attain acceptable grain yield in no-till wheat. Wilkins et al. (1988) also studied the effect of standing stubble density on no-till wheat production. They reported that dry-matter yield at tillering, main stem leaf development, and plant height at harvest decreased with increasing amounts of standing residue and therefore removal or burial of excessive crop residue was critical for good early wheat plant growth. In a three-year study, Cochran et al. (1982) evaluated the effects of various residue management methods on no-till winter wheat production. Although no differences were found in crop yield, residue management method affected the number of tillers produced and the amount of water stored in the soil profile. No-till handbooks intended for growers often emphasize the importance of residue management for successful drill performance, stand establishment, and crop production in conservation tillage systems (Green and Poisson, 1999; Hultgreen, 1999; Smith et al., 2000). General recommendations on residue distribution and sizing techniques are given, but these publications contain limited information about the effectiveness of residue management in heavy crop residues or its impact on crop production. In order to improve no-till cropping system performance, a better understanding of residue management and its impact on machine performance and subsequent crop production is needed. To address this issue, research was conducted to evaluate the effects of various residue management strategies on no-till drill performance in terms of stand establishment, early plant vigor and crop yield. Plant residues resulting from the use of these techniques were characterized by size, concentration, and distribution to quantify the impact of residue condition on subsequent no-till crop production.

Materials and Methods

Experiments were conducted in crop years (CY's) 2000 and 2001 in northeastern Oregon fields that had been seeded to winter wheat the previous year. In CY 2000, eight residue management treatments resulting from using two types of combines, two types of headers and various residue chopping and spreading devices were evaluated (table 1). Combine types included a rotary combine equipped with a flail-type straw spreader and cutterbar header, a cylinder-type combine outfitted with a straw chopper, an aftermarket chaff spreader and a cutterbar header, and a cylinder-type combine equipped with a stripper header and an aftermarket chaff spreader. The first treatment was harvested conventionally with a rotary combine and then the residue was removed by baling. The second residue management treatment was to lower the header height to 20 cm and use the rotary threshing action of the combine to break up the residue. Because the rotary combine was not equipped with a chaff spreader, it left a heavy concentration of chaff and straw on one side of the 7.4-m wide harvested strip. Consequently, this area was divided into two 3.7-m wide treatments designated "in the chaff row" and "outside the chaff row" and represented heavy and light concentrations of residue, respectively. One pair of these plots was seeded directly, while the second pair was disked with a 3.7-m wide tandem disk harrow with 66-cm diameter disk blades to a depth of 7.5 to 10 cm prior to seeding to incorporate some of the residue. The sixth residue management strategy was to use the cutterbar on a cylinder-type combine to cut the residue at a height of 20 cm and the combine's straw chopper and chaff spreader to chop and distribute the residue. A cylinder-type combine equipped with a 3.7-m wide stripper header was also used to establish a tall standing stubble treatment. The final residue management treatment was also harvested with a stripper header, but the residue was cut at ground level, chopped into small pieces, and then blown back onto the plot area with a forage chopper with a 1.8-m wide platform. During operation, the deflector plate on the forage chopper chute was adjusted to the fully down position and angled so that the residue was directed immediately onto the plot area. This treatment simulated using a combine equipped with a super fine straw chopper that would chop straw into short pieces.

Table 1. Residue management treatment descriptions evaluated in crop year 2000.

Treatment	Combine Type	Header Type	Residue Management w/ Combine	Residue Management Post Harvest
1	Rotary	Cutterbar header	None	Baled
2	Rotary	Cutterbar header	In chaff row	None
3	Rotary	Cutterbar header	Outside chaff row	None
4	Rotary	Cutterbar header	In chaff row	Disk
5	Rotary	Cutterbar header	Outside chaff row	Disk
6	Cylinder	Cutterbar header	Straw chopper Chaff spreader	None
7	Cylinder	Stripper	Chaff spreader	None
8	Cylinder	Stripper	Chaff spreader	Forage chopped

To characterize the size, concentration, and distribution of residue on the soil surface prior to seeding, standing stubble and cut distributed residue were collected, processed, and weighed. The method used was patterned after the one developed by Allmaras et al. (1985). The procedure involved mowing a strip of un-harvested wheat approximately 1 m wide at ground level perpendicular to the direction of combine travel and removing all plant material. A 1-m wide canvas apron was then laid in this strip and aligned with the edge of uncut wheat. When the combine passed over the area, all material exiting the combine was deposited on the apron. The apron was partitioned into at least six equal length sections of approximately 0.6 m, and the residue from each section was collected separately, separated by size, and weighed. Straw lengths greater than 18 cm were separated by hand, while straw lengths less than 18 cm were separated from chaff and straw less than 5 cm by running the sample over sets of screens. Standing stubble from a 0.5-m square area adjacent to the apron was cut at ground level to determine un-cut straw density and cutting height. For each residue management treatment, this procedure was replicated twice outside the plot area. The weights of the segregated samples were then averaged and used to calculate residue concentration distribution patterns across the cutting width. Because the total amount of residue collected varied between replications, residue concentrations for each replication were normalized to the overall average residue concentration of all replications by multiplying the individual replication residue concentration by the ratio of the overall average residue concentration to the individual replication concentration. For the baled treatment, residue size, concentration, and distribution were determined by collecting the aboveground dry matter after baling from a 1-m by 7.4-m sample area. Anchored and loose stubble were kept separate and then were sized and weighed. Because it was difficult to separate surface residue from incorporated residue in the disked treatments accurately, residue densities were estimated by assuming that disking would incorporate 55% of the crop residue initially on the soil surface (Shelton et al., 2000). An ANOVA was performed using SAS (SAS Institute Inc., 2003) to determine statistical differences in residue concentration levels between treatments at the P = 0.10 level.

In CY 2000, the study was conducted on a farm located near Helix, Oregon where the average annual precipitation is 380 mm and the soil is a Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxerolls). The average grain yield surrounding the study site was 5.7 t/ha with approximately 9.8 t/ha of residue. Spring and winter plots 3.7 m wide by 61 m long were laid out in a randomized complete block design with four replications and eight treatments in each block. Fall plots were seeded with 50:50 blend of Stephens and Madsen soft white winter wheat with a 3.7 m wide, 30-cm row spacing hoe-type no-till plot drill on 2 November 1999 and 3 November 1999. Application rates were 117 kg/ha of seed and 142 kg/ha of N applied in the form of 177 kg/ha of 16-20-0 with the seed and 248 kg/ha of 46-0-0 placed approximately 7 cm below and 2.5 cm to the side of the seed. Spring plots were seeded 30 March 2000 with the same plot drill and planted to 121 kg/ha of Alpowa spring wheat. Fertilizer rates were 127 kg/ha of N in the form of 113 kg/ha of 16-20-0 placed with the seed and 237 kg/ha of 46-0-0 placed below and to the side of the seed.

After the seedlings had emerged and the date of the last killing frost had past, stand counts were taken and recorded for 1-m length of row for the inner 10 rows of each 12-row plot. The outer two rows of each plot were not counted to avoid edge effects. A random sampling location at least 5 m from either end of the plot was selected for each replication. At the 5-leaf stage of growth, approximately 100 plants were collected from the innermost four rows of each plot at the designated sampling location. The young plants were analyzed for yield potential parameters including main stem Haun growth stage, plant dry weight, and presence of tillers (Klepper et al., 1982). Grain yield was determined by harvesting 5 rows from each 12-row plot with a plot combine and adjusted to 10% moisture content. An ANOVA was performed using SAS (SAS Institute Inc., 2003) to determine statistical differences between the treatment means at the P = 0.10 level.

In CY 2001, a similar type of experiment was conducted on a farm adjacent to the Columbia Plateau Conservation Research Center near Pendleton, Oregon. The soil at the site is a well-drained Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxerolls) and the average annual precipitation is 418 mm. In this experiment, three of the most promising residue management methods from the previous year's experiment were investigated. These included baling and removing the residue, harvesting the residue with a combine equipped with a stripper header and then chopping the residue into small pieces using a forage chopper, and cutting the crop at a height of 20 to 30 cm and using the combine's straw chopper and chaff spreader to evenly distribute the residue (table 2). Two additional techniques were also investigated. One involved harvesting the crop at a cutting height of 40 cm and then flailing the residue post harvest to a height of 12 cm. The other involved harvesting the crop at a height of 40 cm and then cutting the standing stubble with a sickle bar mower to a height of 12 cm. Residue concentration and distribution patterns were measured and analyzed using the methods previously described for the CY 2000 experiment.

The study site yielded 7.1 t/ha of winter wheat in CY 2000 and had approximately 10.5 t/ha of residue. Spring and winter plots 3.7 m wide by 61 m long were laid out in a randomized complete block design with four replications and five treatments in each block. Fall plots were seeded to Stephens winter wheat on 30 October 2000 with a 3.6-m wide, 30-cm row spacing hoe-type no-till drill. Application rates were 112 kg/ha of seed and 173 kg/ha of N in a combination of 112 kg/ha of 16-20-0 placed with the seed and 336 kg/ha of 46-0-0 placed 7 cm below and 2.5 cm to the side of the seed. Alpowa spring wheat was planted with the 3.7 m wide hoe-type plot drill on 15 March 2001. Applications rates were 112 kg/ha of seed and 131 kg/ha of N applied in the form of 112 kg/ha of 16-20-0 with the seed and 245 kg/ha of 46-0-0 below and to the side of the seed. Stand establishment and yield potential parameters were recorded using the methods previously described for the CY 2000 study. Plot yield was obtained by harvesting the inner 9 rows of each 12-row plot with a plot combine.

RESULTS AND DISCUSSION

A summary of the residue concentration, sizing, and distribution results for the CY 2000 trial are presented in table 3. The average initial aboveground residue concentration was 9.8 t/ha. The baling operation removed over 75% of the residue with the remaining 2.3 t/ha of residue nearly equally distributed between standing stubble and on-ground residue. This residue concentration is equivalent to the residue concentration following a 1.4 t/ha crop of winter wheat, assuming wheat produces 112 kg/ha of aboveground residue per 67 kg/ha of grain yield (Smith et al., 2000). It is also below the reported 2.5 to 4.5 t/ha limit for unimpeded no-till drill performance (Erbach et al., 1983; Slattery and Riley, 1996; Siemens et al., 2004). The residue distribution pattern of the combine used for treatments 2 to 5 was skewed with

Table 2. Residue management treatment descriptions evaluated in crop year 2001.

Treatment	Combine Type	Header Type	Residue Management w/Combine	Residue Management Post Harvest
1	Rotary	Cutterbar header	None	Baled
2	Cylinder	Stripper	Chaff spreader	Forage chopped
3	Cylinder	Cutterbar header	Straw chopper Chaff spreader	None
4	Cylinder	Cutterbar header	Straw chopper Chaff spreader	Flailed
5	Cylinder	Cutterbar header	Straw chopper Chaff spreader	Sickle-bar cutter

Table 3. Residue size, concentration, and distribution for the residue management treatments evaluated in crop year 2000.

Treatment	Residue Management w/Combine	Residue Management Post Harvest	Header Height (cm)	Stubble Height (cm)	Residue Concentration Standing ($t\ ha^{-1}$)	Residue Concentration On−Ground ($t\ ha^{-1}$)	Residue Concentration Total ($t\ ha^{-1}$)	On-Ground Residue Weight Distribution L[a] < 5 cm (%)	On-Ground Residue Weight Distribution 5 cm < L < 18 cm (%)	On-Ground Residue Weight Distribution L > 18 cm (%)
1	None	Baled	40	7	1.0 c[b]	1.3 g	2.3 f	61 b	35 bc	4 d
2	In chaff row	None	20	20	2.8 b	10.3 a	13.1 a	39 c	55 a	6 cd
3	Outside chaff row	None	20	20	2.8 b	3.7 e	6.5 c	63 b	29 c	8 bc
4	In chaff row	Disk[c]	20	−−−	0 d	5.9 d	5.9 d	−−−	−−−	−−−
5	Outside chaff row	Disk	20	−−−	0 d	2.9 f	2.9 e	−−−	−−−	−−−
6	Straw chopper Chaff spreader	None	20	20	2.8 b	7.0 c	9.8 b	48 c	40 b	12 a
7	Chaff spreader	None	Stripper	61	8.5 a	1.3 g	9.8 b	64 b	26 cd	10 ab
8	Chaff Spreader	Forage chopped	Stripper	7	1.0 c	8.8 b	9.8 b	79 a	17 d	4 d
Error Mean Square					0.02	0.03	0.02	40.4	24.7	3.2

[a] L is defined as the length of a piece of wheat plant residue.
[b] Within columns, means followed by the same letter are not significantly different by Duncan's new multiple range test (P = 0.10).
[c] Residue densities after disking were estimated by assuming that disking would incorporate 55% of the residue on the soil surface (Shelton et al., 2000).

heavy accumulations of chaff and straw concentrated on one side of the header (fig. 1). Maximum concentration of residue was nearly 22 t/ha in the chaff row, while the minimum residue concentration outside the chaff row was approximately 4 t/ha. Although this amount of variability seems excessive, Allmaras et al. (1985) reported similar uneven residue distribution patterns with residue concentrations ranging from 4.7 t/ha to nearly 21 t/ha for rotary combines with standard flail spreading mechanisms. On-ground residue concentration in the chaff row and out of the chaff row averaged 10.3 and 6.5 t/ha, respectively (table 3). Less than 8% of the weight of on-ground residue in either treatment was straw greater than 18 cm in length, indicating that the rotary threshing mechanism was effective in reducing straw length. As a residue management treatment, the disking operation left no anchored standing stubble and incorporated some of the aboveground residue. Residue concentration was estimated to be 5.9 t/ha in the chaff row and about 2.9 t/ha outside the chaff row. The residue management treatment of harvesting with a combine equipped with a straw chopper and chaff spreader also had a relatively non-uniform distribution pattern (fig. 2). Residue was concentrated on one side of the combine, partially due to high crosswinds of approximately 16 to 24 km/h at the time of testing. Maximum residue concentration was approximately 15 t/ha while the minimum concentration was 4 t/ha. The uneven residue distribution ratio (URDR) of 3.8, defined by Allmaras et al. (1985) as the maximum total residue divided by the minimum total residue, compares favorably with the 3.8 URDR of similarly equipped combines in the Allmaras et al. (1985) study. Due to the low header height of 20 cm, over 70% of residue was processed by the combine. The straw chopper was effective in reducing straw length with 48% of the cut residue being chaff and straw less than 5 cm in length, 40% being straw less than 18 cm in length, and 12% being straw greater than 18 cm in length. The treatment harvested with a combine equipped with a stripper header and chaff spreader left 87% of the residue as 61-cm tall standing stubble and the remaining chaff and straw fairly evenly distributed across the header width (table 3, fig. 3). Of the 1.3 t/ha of on-ground residue, 36% by weight was straw greater than 5 cm in length indicating that the stripper header harvests some straw in addition to wheat heads. A good representation of a super fine straw chopper was obtained, as the forage chopper was effective in reducing stripper header harvested straw length to about 4 cm in length. Nearly 80% of the 8.8 t/ha of on-ground residue was classified as chaff or straw less than 5 cm in length and fairly evenly spread (table 3, fig. 4). Residue distribution was also more centered about the midpoint of the header as compared to the other treatments

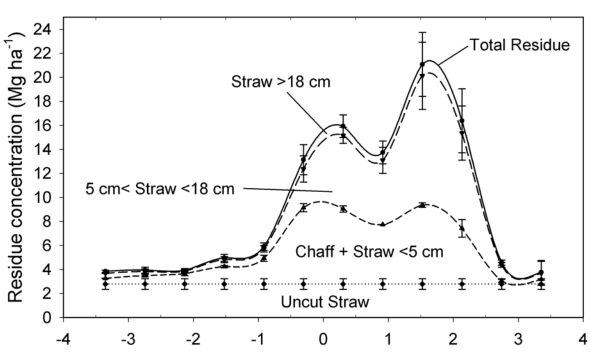

Figure 1. Residue distribution pattern resulting from harvesting a 5.7-t/ha crop of winter wheat with 9.8 t/ha of residue with a 7.4-m wide rotary-type combine equipped with a single flail-type spreader and no chaff spreader. Error bars indicate one standard error of the mean (n = 2).

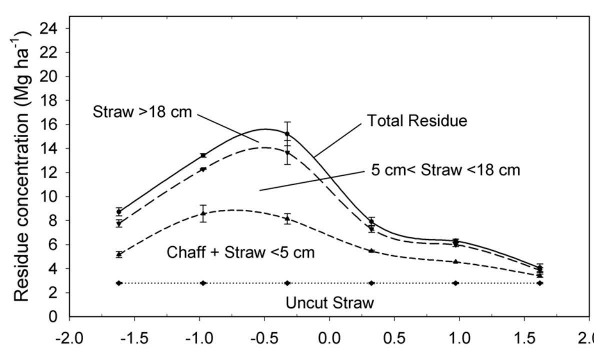

Figure 2. Residue distribution pattern resulting from harvesting a 5.7-t/ha crop of winter wheat with 9.8 t/ha of residue with a 3.7-m wide cylinder-type combine equipped with a straw chopper and chaff spreader. Error bars indicate one standard error of the mean (n = 2).

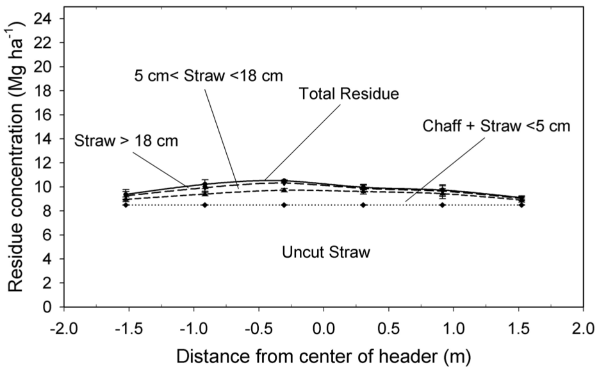

Figure 3. Residue distribution pattern resulting from harvesting a 5.7-t/ha crop of winter wheat with 9.8 t/ha of residue with a 3.7-m wide cylinder-type combine equipped with a stripper header and chaff spreader. Error bars indicate one standard error of the mean (n = 2).

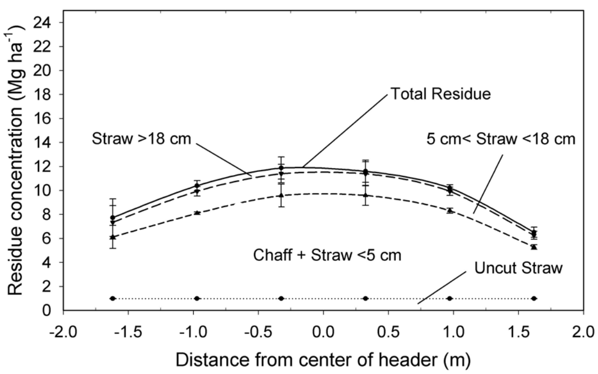

Figure 4. Residue distribution pattern resulting from harvesting a 5.7-t/ha crop of winter wheat with 9.8 t/ha of residue with a 3.7-m wide cylinder-type combine equipped with a stripper header and chaff spreader and then chopping the standing stubble with a 1.8 m wide forage chopper. Error bars indicate one standard error of the mean (n = 2).

since the residue exiting the forage chopper had a high velocity and was therefore less affected by crosswinds. Approximately 17% of the on-ground residue was straw less than 18 cm in length with the remaining 4% being straw greater than 18 cm in length. Because the cutting height was only 7 cm, standing stubble concentration was less than 1 t/ha.

Removing residue by baling provided the highest stand establishment, most advanced early plant growth, and highest yield of all the treatments in the CY 2000 winter wheat trial (table 4). Stand establishment was over 30% greater in the baled treatment as compared to the high residue concentration within chaff row treatment and the disked treatment outside the chaff row. These differences were statistically significant at the 90% level of confidence. Young plants in the baled treatment also had a significantly more advanced main stem Haun growth stage, were 40% heavier, and had over 37% more tillers than plants in the other residue treatments. These results suggest that excessive crop residues on the soil surface impede stand establishment and early plant growth in no-till. Despite these early advantages, yields in the baled treatment were not significantly different than the other treatments where the ground was not tilled. This result may be explained by the ability of wheat to compensate for low plant stands, early plant growth and tillering when growing conditions are favorable during grain fill as was the case in CY 2000 (Greenwalt, 2004a, 2004b). Wilkins et al. (1988) described similar results and reported that although the presence of surface residue reduced main-stem leaf development, tillering and above-ground dry weights at late tillering, yields were not significantly different than those of burnt plots due to highly favorable growing conditions from anthesis to maturity. Additionally, Tompkins et al. (1991) reported that at intermediate plant densities, no-till winter wheat yield was not significantly affected by seeding rate and therefore plant populations. Yields in the two disked treatments were the lowest yields of any treatment and significantly lower than the baled treatment. Lower yields in the disked treatment were presumably due to loss of soil moisture by tillage, but this was not measured. Another significant result was that stand establishment outside the chaff row was 21% greater than inside the chaff row, further indicating that heavy concentrations of residue on the soil surface impedes seedling emergence. Comparing residue management treatments 6 and 8 where 9.8 t/ha of residue was left on the soil surface, there were few significant differences in stand establishment, seedling vigor, and crop yield. It is therefore not possible to draw meaningful conclusions. Treatment 7 also had 9.8 t/ha of residue on the soil surface, but the crop had been harvested with a stripper header equipped combine and the stubble was left standing tall. This residue management method was considered unacceptable for hoe-type no-till drills since the drill plugged with residue shortly after entering the plot in all four replications.

Table 4. Stand establishment, early plant growth characteristics, and grain yield for winter wheat near Helix, Ore., crop year 2000, when planted with a hoe-type no-till drill into 9.8 t/ha of residue that had been managed in different ways.

	Residue Management		Stubble Height	Stand Count	Main Stem Haun	Plant Weight	Tiller 1 Presence	Tiller 2 Presence	Yield
Treatment	w/Combine	Post Harvest	(cm)	(plants m^{-2})	(stage)	(gm)	(%)	(%)	(t ha^{-1})
1	None	Baled	5	207 a[a]	5.6 a	0.30 a	45 a	85 a	5.8 a
2	In chaff row	None	20	157 c	5.2 bc	0.18 bc	16 b	43 b	5.6 ab
3	Outside chaff row	None	20	190 ab	5.1 bc	0.21 b	18 b	48 b	5.7 ab
4	In chaff row	Disk	−−−	177 abc	5.3 b	0.17 bc	11 b	52 b	5.4 bc
5	Outside chaff row	Disk	−−−	159 bc	5.1 bc	0.18 bc	25 b	56 b	5.2 c
6	Straw chopper Chaff spreader	None	20	181 abc	5.3 b	0.21 b	22 b	62 b	5.7 ab
7	Chaff spreader	None	61	NA[b]	NA	NA	NA	NA	NA
8	Chaff Spreader	Forage chopped	7	187 abc	5.0 c	0.15 c	13 b	45 b	5.7 ab

[a] Within columns, means followed by the same letter are not significantly different by Duncan's new multiple range test (P = 0.10).
[b] Data not available due to unacceptable drill plugging.

Table 5. Stand establishment, early plant growth characteristics and grain yield for spring wheat near Helix, Oregon, crop year 2000, when planted with a hoe-type no-till drill into 9.8 t/ha of residue that had been managed in different ways.

Treatment	Residue Management w/Combine	Residue Management Post Harvest	Stubble Height (cm)	Stand Count (plants m^{-2})	Main Stem Haun (stage)	Plant Weight (gm)	Tiller 1 Presence (%)	Tiller 2 Presence (%)	Yield (t ha^{-1})
1	None	Baled	5	180 a[a]	5.5 ab	0.42 a	96 a	95 a	4.6 a
2	In chaff row	None	20	123 cd	5.0 c	0.28 c	99 a	100 a	4.2 bc
3	Outside chaff row	None	20	164 ab	5.6 a	0.42 a	94 ab	98 a	4.4 ab
4	In chaff row	Disk	−−−	119 d	5.3 b	0.31 bc	90 b	93 a	3.7 d
5	Outside chaff row	Disk	−−−	132 cd	5.6 a	0.42 a	94 ab	99 a	3.9 cd
6	Straw chopper Chaff spreader	None	20	134 cd	5.4 b	0.36 ab	98 a	98 a	4.4 ab
7	Chaff Spreader	None	61	137 cd	5.4 b	0.41 a	96 a	96 a	3.9 cd
8	Chaff Spreader	Forage chopped	7	145 bc	5.4 b	0.36 ab	96 a	96 a	4.2 bc

[a] Within columns and treatment category, means followed by the same letter are not significantly different by Duncan's new multiple range test (P = 0.10).

Similar results were found in the CY 2000 spring wheat trial. In the treatment where the residue was removed by baling, stand establishment was 24% to 51% higher than in any other treatment (table 5). The only exception being the conventionally harvested out of chaff row treatment where the residue concentration was also low. These two low residue concentration treatments had the most, or not significantly different from the most, advanced main stem Haun growth stage, highest plant weight, most tillers, and highest yield of any treatment, indicating that concentrations of residue not only hinder seedling emergence, but also negatively affect early plant growth and subsequent crop yield. The effect of stubble height and size of chopped residue can be examined by comparing the results of treatments 6, 7, and 8. Among these treatments, stand establishment, early plant growth, and tillering were not significantly different. Yield of the tall standing stubble treatment 7 harvested with the stripper header was reduced by 13% (0.5 t/ha) as compared to treatment 6 where the straw chopper and chaff spreader were used. One possible explanation for this is that the tall standing stubble intercepted more light at advanced growth stages than the shorter standing stubble treatment and therefore yield potential was suppressed. It should be noted that seeding into the tall standing stubble treatment resulted in unacceptable drill plugging in the fall, but not in the spring. An explanation for this is that the residue had decomposed over the winter and therefore had less strength to push residue ahead of the furrow opener and promote drill plugging. The effect of poor combine residue distribution can be determined by comparing the in and out of the chaff row treatments which had significantly different levels of on-ground and total residue concentrations (table 3). Stand establishment and plant weight were significantly greater by 33% and 50%, respectively, outside the chaff row where residue concentration was 6.5 t/ha as compared to in the chaff row where residue concentration exceeded 13 t/ha. Main stem growth was also suppressed, but yields were not significantly different, again possibly due to favorable late season growing conditions. Another possibility is that the difference in plant populations was not great enough to significantly influence yield since Ciha (1983) reported that spring wheat yield was not consistently affected by seeding rates ranging from approximately 97 to 266 seeds/m^2. Incorporating the residue by disking resulted in low plant stands and significantly lower crop yield as compared to the non-tilled treatments (table 5). Stand establishment was reduced because in loose soil, openers on the rear ranks of the drill threw soil onto adjacent rows that had already been seeded. This increased effective seeding depth and inhibited seedling emergence. Low yields in the disked treatments were attributed to a combination of low plant stands and loss of soil moisture by the tillage.

Baling reduced the residue concentration in the CY 2001 plots from 10.5 to 2.2 t/ha (table 6). This residue concentration is similar to the CY 2000 results where the post baling residue density was 2.3 t/ha and is below the reported 2.5- to

Table 6. Residue size, concentration, and distribution for the residue management treatments evaluated in crop year 2001.

Treatment	Residue Management w/Combine	Residue Management Post Harvest	Header Height (cm)	Stubble Height (cm)	Residue Concentration Standing (t ha^{-1})	Residue Concentration On−Ground (t ha^{-1})	Residue Concentration Total (t ha^{-1})	On-Ground Residue Weight Distribution L[a] < 5 cm (%)	On-Ground Residue Weight Distribution 5 cm < L < 18 cm (%)	On-Ground Residue Weight Distribution L > 18 cm (%)
1	None	Baled	40	5	0.5 d[b]	1.7 d	2.2 b	59 b	39 ab	2 d
2	Chaff Spreader	Forage chopped	Stripper	23	2.5 b	8.0 b	10.5 a	79 a	19 c	2 d
3	Straw chopper Chaff spreader	None	30	30	3.8 a	6.7 c	10.5 a	49 bc	31 b	20 b
4	Straw chopper Chaff spreader	Flailed	40	12	1.3 c	9.2 a	10.5 a	42 cd	47 a	11 c
5	Straw chopper Chaff spreader	Sickle−bar cutter	40	20	2.1 b	8.4 b	10.5 a	29 d	15 c	56 a
Error Mean Square					0.08	0.08	0.08	41.4	27.4	10.1

[a] L is defined as the length of a piece of wheat plant residue.
[b] Within columns, means followed by the same letter are not significantly different by Duncan's new multiple range test (P = 0.10).

4.5-t/ha limit for unimpeded no-till drill performance (Erbach et al., 1983; Slattery and Riley, 1996; Siemens et al., 2004). Because the same stripper header equipped combine and forage chopper were used in CY 2001 as in CY 2000, the residue concentration and distribution patterns resulting from the use of these machines were also very similar. Forage chopping the stripper header harvested wheat stubble at a header height of 23 cm left 2.5 t/ha of standing residue and 8.0 t/ha as cut residue on the ground. Nearly 80% of the weight of on-ground residue was classified as chaff and pieces of straw less than 5 cm in length. One equipment change made during 2001 was to modify the straw chopper by elongating the distribution fins to provide the more uniform distribution pattern shown in figure 5. Maximum residue concentration was 11.5 t/ha while the minimum concentration was 7.8 t/ha resulting in a maximum difference of 3.7 t/ha and an URDR of 1.5. A low URDR is important since Allmaras et al. (1985) suggested that a URDR of less than 1.5 is needed to avoid the phytotoxic and poor tillering effects caused by excessive residue concentrations in no-till wheat. Flailing 40-cm tall standing residue to a height of 12 cm resulted in a treatment that was similar to the straw chopper treatment number 3, but with less standing stubble due to the lower cutting height. The flail was more effective than the straw chopper at reducing straw length as nearly 90% of the on-ground residue weight was chaff and straw shorter than 18 cm as compared to 80%. Although using a sickle bar cutter to cut 40-cm standing stubble to a height of 20 cm resulted in concentrations of standing stubble and on-ground residue that were statistically different from the flailed treated, the magnitude of the difference was only 0.8 t/ha (table 6). A practical significant difference between the two treatments was that in the sickle bar cutter treatment, 56% of the on-ground residue was straw greater than 18 cm in length as compared to only 11% in the flailed treatment.

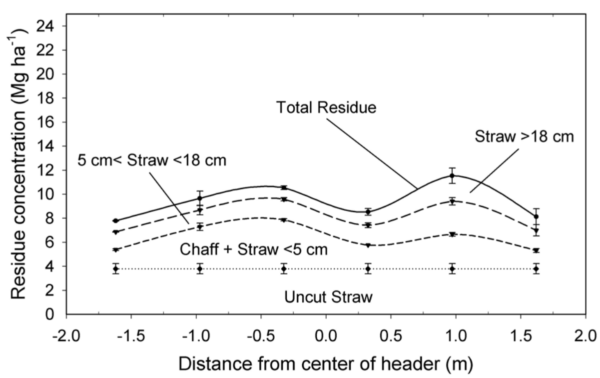

Figure 5. Residue distribution pattern resulting from harvesting a 7.1-t/ha crop of winter wheat with 10.5 t/ha of residue with a cylinder-type combine equipped with a modified straw chopper and chaff spreader. Error bars indicate one standard error of the mean (n = 2).

In the winter wheat seeding trial in CY 2001, removing the residue by baling resulted in the highest stand establishment of 153 plants/m^2 (table 7). This result was more than 50% higher than the stand establishment obtained in any other treatment and was significant at the 90% level of confidence. Increased emergence in the baled treatment was observed to be due to the low residue concentrations as compared to the other treatments where high residue concentrations tended to cover the seed row and inhibit seedling survival. The baled treatment also showed superior plant growth, weight, and tillering as compared to the other treatments, although these differences were not always statistically significant (table 7). Despite these early advantages, yields of the baled treatment were within 0.3 t/ha of those obtained from the other treatments and not significantly different. Sizeable increases may have occurred if yields were not suppressed due to lack of precipitation and high temperatures during the critical grain filling period in late May and early June (Greenwalt, 2004a, 2004b) or if the differences in stand establishment had been greater. Amongst the other residue management methods where 10.5 t/ha of residue was left on the soil surface, there were no significant differences in stand establishment, plant growth, plant weight, first tiller presence, or crop yield.

The only exception was the treatment where the sickle bar cutter was used to cut 40-cm standing stubble to a height of 20 cm. This method resulted in unacceptable drill plugging in two of four replications and no data were taken. This result conflicts with the residue management recommendation that in order to prevent drill plugging, stubble height should not exceed seed row spacing since row spacing was 30 cm and stubble height was only 20 cm (Green and Poisson, 1999; Hultgreen, 1999). An explanation for this is that combine threshing and residue sizing methods such as flailing not only reduce straw length, they also reduce straw strength by crushing the plant's stem walls. Cutting standing stubble with a sickle-bar cutter maintains the structural integrity of the straw and therefore its axial strength. Thus, when seeding into sickle-bar cut stubble, straw lodged on the opener has strength to push residue in front of it and promote drill plugging. Another reason is that the sickle bar cutter

Table 7. Stand establishment, early plant growth characteristics and grain yield for winter wheat near Pendleton, Oregon, crop year 2001, when planted with a hoe-type no-till drill into 10.5 t/ha of residue that had been managed in different ways.

Treatment	Residue Management w/Combine	Residue Management Post Harvest	Stubble Height (cm)	Stand Count (plants m^{-2})	Main Stem Haun (stage)	Plant Weight (gm)	Tiller 1 Presence (%)	Tiller 2 Presence (%)	Yield (t ha^{-1})
1	None	Baled	5	153 a[a]	6.0 a	0.79 a	55 a	93 a	3.4 a
2	Chaff spreader	Forage chopped	23	100 b	5.8 a	0.60 b	53 a	90 ab	3.7 a
3	Straw chopper Chaff spreader	None	30	97 b	5.9 a	0.62 b	51 a	82 bc	3.5 a
4	Straw chopper Chaff spreader	Flailed	12	100 b	5.8 a	0.54 b	47 a	78 c	3.4 a
5	Straw chopper Chaff spreader	Sickle-bar cutter	20	NA[b]	NA	NA	NA	NA	NA

[a] Within columns, means followed by the same letter are not significantly different by Duncan's new multiple range test (P = 0.10).
[b] Data not available due to unacceptable drill plugging.

Table 8. Stand establishment, early plant growth characteristics and grain yield for spring wheat near Pendleton, Oregon, crop year 2001, when planted with a hoe-type no-till drill into 10.5 t/ha of residue that had been managed in different ways.

Treatment	Residue Management w/Combine	Residue Management Post Harvest	Stubble Height (cm)	Stand Count (plants m^{-2})	Main Stem Haun (stage)	Plant Weight (gm)	Tiller 1 Presence (%)	Tiller 2 Presence (%)	Yield (t ha^{-1})
1	None	Baled	5	147 a[a]	5.3 a	0.29 a	64 a	88 a	3.6 a
2	Chaff spreader	Forage chopped	23	122 b	5.0 ab	0.22 b	65 a	88 a	3.4 a
3	Straw chopper Chaff spreader	None	30	117 b	4.8 b	0.22 b	60 a	81 a	3.4 a
4	Straw chopper Chaff spreader	Flailed	12	122 b	4.7 b	0.21 b	63 a	76 a	3.6 a
5	Straw chopper Chaff spreader	Sickle-bar cutter	20	NA[b]	NA	NA	NA	NA	NA

[a] Within columns, means followed by the same letter are not significantly different by Duncan's new multiple range test (P = 0.10).
[b] Data not available due to unacceptable drill plugging.

treatment had substantially more long, loose straw than the other treatments. When disturbed, these long pieces of straw tended to bridge on each other, build up around the opener and eventually plug the drill. In the other treatments, shorter straw flowed more easily around the opener, and plugging problems were not encountered. A drawback of chopping straw into short pieces is that it increases energy requirements.

Results of the CY 2001 spring wheat seeding trials were very similar to the CY 2001 winter wheat trials as shown in table 8. In the baled treatment where the residue concentration was reduced, stand establishment was 20% higher as compared to the other treatments. This increase was again attributed to fewer piles of residue covering the seed row. As in CY 2000, reduced residue levels in the baled treatment resulted in increased early plant growth and weight as compared to the other treatments, but did not significantly increase yield (table 8). Significant differences might have occurred if stand establishment differences were greater or if cereal crop yields were not compromised by Hessian fly infestation (Smiley et al., 2002). The treatment where the 40-cm tall standing stubble was simply cut in half with a sickle-bar cutter was again abandoned due to unacceptable drill plugging in two of the plots. It was concluded that this lower energy residue management method was not a viable option for no-till seeding in high concentrations of crop residue. Other methods that size residue into smaller pieces and/or crush stem walls are needed for trouble-free drill operation. No differences in plant stand, plant growth, plant weight, tillering, or crop yield were found between the other residue management methods used. Because the main difference between these treatments was the length of chopped straw, these results in conjunction with previously stated results indicate that cut straw length is not a significant factor for no-till drill performance and crop production as long as the majority of straw has been chopped to a length of less than 18 cm. Fine straw chopping systems did not improve crop production and therefore would increase power requirements unnecessarily.

CONCLUSIONS

Various residue management methods ranging from leaving tall standing stubble, to chopping the residue into various length pieces to removing the residue by baling were investigated to determine their effect on hoe-type no-till drill performance and production of winter and spring wheat. Results of the experiments showed that residue management method can have a significant effect on hoe-type no-till drill operation and performance in terms of drill plugging, winter and spring wheat stand establishment, early plant growth, tillering, and to a lesser extent, crop yield. In three of the four trials conducted over a two year period, reducing residue concentration to less than 2.3 t/ha by baling and removing residue resulted in significant (P = 0.10) increases in stand establishment and seedling dry weight as compared to treatments where the full quantity of residue was left on the soil surface. Increases in stand establishment and plant weight ranged from 20% to 58% and 22% to 46% respectively. Increases in stand establishment were attributed to fewer piles of residue covering the seed row. Despite these advantages, consistent yield increases were not found due to the ability of wheat to compensate for low plant populations, favorable growing conditions during grain fill in CY 2000, and a crop yield limiting infestation of Hessian fly during CY 2001. Additional studies should be conducted to determine the effect of high residue concentrations on no-till yield during normal years. Although reducing residue concentrations by baling provided superior drill performance in terms of stand establishment, early plant growth and vigor, annual removal of crop residues may not be environmentally sustainable (Douglas and Albrecht, 2000). Alternative residue management methods and/or improved no-till drill designs are needed for no-till crop production to reach its full potential in heavy crop residues.

Another factor causing impeded drill performance was concentrated rows of residue after combine harvest. Poor combine residue distribution systems were found to cause residue concentrations to vary across a header swath by more than a factor of 5. Outside the chaff row, winter and spring wheat stand establishment were 21% and 33% greater, respectively, than those obtained in chaff rows where residue concentrations were significantly higher. Spring wheat plants in the chaff row also had significantly less advanced plant growth stage and lower plant weight than plants outside the chaff row. Although not always statistically significant, when residue was more uniformly spread across the header width, increases in stand establishment, plant growth and weight and yields were obtained. These results suggest that in order to obtain optimum crop production in no-till systems, combines and other equipment must be designed to uniformly distribute crop residue.

Residue length and condition had a significant influence on drill operation in terms of plugging. Unacceptable drill plugging occurred when seeding into 61-cm tall standing stubble harvested with a stripper header. High incidences of drill plugging also occurred when seeding into heavy concentrations of loose straw greater in length than 18 cm. In these trials, a sickle bar cutter was used to cut 40-cm tall standing stubble to a height of 20 cm and structural integrity of the straw was maintained. Successful drill operation was achieved in crop residues exceeding 9.8 t/ha when stubble height was less than or equal to row spacing and the majority of cut straw was uniformly distributed and cut into pieces less than 18 cm in length. For these treatments, residue was sized and distributed by a combine equipped with a straw chopper and chaff spreader and stubble height was controlled by header height, or by a flailing operation post harvest. Comparing these treatments to baled plots, stand establishment and early plant growth were reduced in three of the four trials conducted over a two-year period, however crop yields were not significantly different. Using combines equipped with straw choppers and chaff spreaders and flailing post harvest may therefore be acceptable alternatives to baling for commercial no-till crop production. Additional years of study during periods with different weather and pest conditions are needed, however, to substantiate this claim. Length of cut straw did not significantly influence stand establishment, early plant growth, tillering, or crop yield. Fine straw chopping systems are therefore not needed and increase power requirements unnecessarily.

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